

Köppen in Bartholomew's *Atlas*, which in turn were generalized from Meldrum, long director of the Mauritius Observatory. The wider lines indicate that three or more storms followed approximately that course in a 35-year period. The numeral at the end of the line indicates the number of storms along that track in that period. Köppen's charts have been combined and modified to aid in legibility and have been supplemented by several notable tracks shown in *Ein Atlas für den Indischen Ozean, Deutsche Seewarte*, 1891. The latter tracks

are dated as to month, though not as to year. Köppen's tracks are dated only as to season, November and December, January to March, and April to May.

This chart and foregoing data lend little support to the oft-repeated generalization that tropical cyclones originate in a few restricted areas on the western sides of oceans at the time when the doldrums are farthest from the Equator. Many other widely accepted generalizations as to tropical cyclones appear unsafe in the light of the fuller data being gathered.

TROPICAL CYCLONES IN THE NORTHEAST PACIFIC, BETWEEN HAWAII AND MEXICO.

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Redfield, in his paper on cyclones of the Pacific, forming a part of Commodore Perry's *Narrative of Expedition to Japan*, devotes six pages to the northeast Pacific,¹ and presents a chart showing the approximate tracks of 13 cyclones mostly in the region just west of Mexico, but partly near Hawaii. In the *Segelhandbuch für den Stillen Ozean*² there is a list of 45 storms occurring in that region between 1832 and 1892, no mention being made however, of those described by Redfield.

No mention of tropical cyclones occurring in this region between 1892 and 1915 has come to light except that the courses of six are traced by Hurd.³

Severe storms occurring in September, 1915 and September, 1918, are described in the MONTHLY WEATHER REVIEW.⁴

Since August, 1921, brief mention of four tropical cyclones has been made in the same journal.⁵

The following list includes the 70 storms mentioned in these sources of information:

List of tropical cyclonic storms in the northeast Pacific (west of Mexico and Central America and east of the longitude of the Hawaiian Islands.)

Year.	Month.	Place of origin, or first record.		Source of information.
		North latitude.	West longitude.	
1832	December	13	148	D. S. H.
1839	Nov. 1	23	108	D. S. H.
1840	do	22	105	D. S. H.
1842	October	15	93	D. S. H.
1843	Sept. 23	15	139	Redfield.
1847	Oct. 24	17	a 108	Redfield.
1849	June 21-22	16	110	Redfield.
1850				Redfield.
1850	June 24	16	107	Redfield.
1850	Aug. 5	14	b 117	Redfield.
1850	Sept. 9-11	15	100	Redfield.
1850	Sept. 26	26	123	Redfield.
1850	Oct. 1-6	18	104	Redfield.
1850	Oct. 3	14	c 117	Redfield.
1850	October	17	105	D. S. H.
1851	Sept. 16	15	120	D. S. H.
1851	October	21	107	D. S. H.
1851	Oct. 21	22	d 110	Redfield.
1852	July 10-19	15	e 115	D. S. H.
854	Oct. 5	28	135	D. S. H.

a NNE.

b From N.-W.-S.

c SW.-SE.-E.-N.-W.-SW.

d SE.-NE.

e From N.

¹ William C. Redfield: Vol. II, 1856, Sen. Doc. 79, pp. 354-359.

² *Deutsche Seewarte*, Hamburg, 1897, p. 269.

³ Willis E. Hurd: Cyclonic storms and typhoons of the north Pacific, article on the reverse of *Meteorological Charts of the north Pacific*, U. S. Weather Bureau, January, March, and April, 1913.

⁴ J. H. Kimball: A Pacific hurricane of September, 1915; *MO. WEATHER REV.*, vol. 43, p. 486; and F. G. Tingley: Tropical cyclone of Sept. 14-17, 1918, just west of Mexico; *MO. WEATHER REV.*, 44: 568.

⁵ F. G. Tingley, *MO. WEATHER REV.*, 49: 518, 579, 581; and 50: 99.

List of tropical cyclonic storms in the northeast Pacific (west of Mexico and Central America and east of the longitude of the Hawaiian Islands)—Con.

Year.	Month.	Place of origin, or first record.		Source of information.
		North latitude.	West longitude.	
1855	June	20	105	Redfield.
1855	Aug. 3-6	18	109	D. S. H.
1855	Aug. 8-9	15	f 117	Redfield.
1855	Sept. 4	20	g 122	Redfield.
1857	June 20	11	110	D. S. H.
1857	Sept. 6	19	121	D. S. H.
1858	Aug. 17	13	115	D. S. H.
1858	Nov. 21	21	174	D. S. H.
1859	Sept. 10	16	99	D. S. H.
1865	July 25	10	109	D. S. H.
1870	June 17	18	106	D. S. H.
1870	Sept. 21-24	17	141	D. S. H.
1871	July 3	16	117	D. S. H.
1874	Nov. 19	16	161	D. S. H.
1877	Nov. 5	14	123	D. S. H.
1880	July 6	20	120	D. S. H.
1880	Oct. 13	18	111	D. S. H.
1882	July 31	13	118	D. S. H.
1882	Sept. 7	14	105	D. S. H.
1883	Sept. 21-23	20	105	D. S. H.
1883	Oct. 3	23	106	D. S. H.
1884	Sept. 28-30	17	107	D. S. H.
1884	Oct. 23	24	107	D. S. H.
1885	July 31	20	130	D. S. H.
1885	Sept. 12	23	128	D. S. H.
1885	Oct. 5-6	24	108	D. S. H.
1885	Oct. 25	21	106	D. S. H.
1889	Sept. 19	16	95	D. S. H.
1887	July 6	20	114	D. S. H.
1887	Oct. 3-6	17	107	D. S. H.
1888	Aug. 9-10	15	120	D. S. H.
1888	Aug. 13-14	12	120	D. S. H.
1888	Sept. 10-11	17	106	D. S. H.
1889	Sept. 20	23	107	D. S. H.
1890	Aug. 2-3	14	122	D. S. H.
1890	Aug. 18-19	16	124	D. S. H.
1891	Aug. 2	16	118	D. S. H.
1891	Aug. 7	11	107	D. S. H.
1892	July 19	20	117	D. S. H.
1902	Dec. 23-Jan. 2	21	158	Hurd. A
1904	Nov. 26-Dec. 4	18	161	Hurd.
1904	Dec. 23-30	15	156	Hurd.
1906	May 3-10	12	153	Hurd.
1906	Oct. 2-9	18	154	Hurd.
1906	Nov. 6-13	20	157	Hurd.
1915	Sept. 4	15	110	M. W. R., 43: 486.
1918	Sept. 15-16	18	105	M. W. R., 46: 568.
1921	Sept. 24-30	20	105	M. W. R., 49: 518.
1921	Oct. 4	22	156	M. W. R., 49: 579.
1921	Oct. 9	17	102	M. W. R., 49: 581.
1922	Feb. 1			M. W. R., 50: 99.

f NE.-NNW.-WNW.-SW.

g SE.

A W. E. Hurd: Article, Cyclonic storms and typhoons of the north Pacific, U. S. Weather Bureau, January, March, and April, 1913.

The monthly distribution of these storms is shown in Table 1. All but two have occurred in the six-month period June to November, inclusive. September with 28 per cent is the stormiest month, but October with 25 per cent is only slightly behind.

TABLE 1.—Monthly distribution of the foregoing storms between Hawaii and Central America.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Number.....	0.	1	0	0	0	5	8	10	18	16	5	1	64
Per cent of total.....	0	1.6	0	0	0	7.8	12.5	15.6	28.1	25.0	7.8	1.6	100

TABLE 2.—Tropical cyclones of the northeast Pacific—Region of origin or first record of storms for 1832–1922, classified according to months and 5° squares.

Month.	N.	90-95.	95-100.	100-105.	105-110.	110-115.	115-120.	120-125.	125-130.	130-135.	135-140.	140-145.	145-150.	150-155.	155-160.	160-165.	170-175.	Total.
May.....	10-15	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	1
June.....	10-15	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	1
15-20	...	...	...	...	2	...	1	...	...	...	...	...	...	...	...	...	...	3
Total.....	...	...	...	...	2	1	1	...	...	...	...	...	...	...	...	...	...	4
July.....	10-15	...	...	...	1	1	...	...	...	...	...	...	...	...	...	...	...	3
15-20	...	...	...	...	...	2	...	...	...	...	...	...	...	...	...	...	...	3
20-25	...	...	...	...	1	1	...	1	...	...	...	...	...	...	...	...	...	3
Total.....	...	...	...	...	1	2	4	...	1	...	...	...	...	...	...	...	...	8
Aug.....	10-15	...	...	...	1	5	1	...	...	...	...	...	...	...	...	...	...	7
15-20	...	...	...	...	1	1	1	...	...	...	...	...	...	...	...	...	...	3
Total.....	...	...	...	...	1	1	6	2	...	...	...	...	...	...	...	...	...	10
Sept.....	10-15	1	2	...	...	1	...	...	...	1	...	...	...	...	...	...	...	5
15-20	...	1	3	2	...	1	1	...	...	1	...	...	...	...	...	...	...	9
20-25	...	...	1	...	...	1	1	2	...	...	...	...	...	...	...	...	...	4
Total.....	...	1	6	2	...	2	2	2	...	1	1	...	...	...	...	...	...	18
Oct.....	10-15	1	...	...	...	1	...	...	...	...	...	...	...	2	...	...	...	2
15-20	...	...	2	3	...	...	...	...	...	...	...	...	...	...	1	...	...	7
20-25	...	...	...	5	1	...	...	...	...	...	...	...	...	...	...	...	...	1
25-30	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...	...	1
Total.....	...	1	2	8	1	1	...	...	...	1	...	...	...	2	1	...	...	17
Nov.....	10-15	...	...	...	...	...	1	...	...	...	...	...	...	...	...	...	...	1
15-20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	...	2
20-25	...	...	...	2	...	...	...	...	...	...	...	...	...	...	1	1	...	4
Total.....	...	...	...	2	...	...	1	...	...	...	...	...	...	...	1	2	1	7
Dec.....	10-15	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	1
15-20	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	0
20-25	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2
Total.....	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	2	...	3
Grand total.....	2	1	8	16	5	14	5	3	0	2	1	1	3	4	2	1	...	68

Table 2 indicates the approximate area of origin or of first report of these storms. This table is a revision of the one by Schück.⁶ While he studies only the 45 storms listed in the *Segelhandbuch*, here 68 storms are considered, two of the 70 storms given in the foregoing list not being readily located from information at hand.

Figure 1 shows the approximate courses of about 60 tropical storms in the region under consideration. These tracks were obtained from the several sources (1), the chart by Redfield,⁷ (2) a chart in the *Segelhandbuch für den Stillen Ozean*,⁸ (3) A large number of the tracks were copied from the official German atlas of the Pacific.⁹ (4) Several tracks are traced on Monthly Meteorological Charts¹⁰ and Pilot Charts¹¹ for the North Pacific. (5) Several recent tracks are from the MONTHLY WEATHER REVIEW, especially those for 1915, 1918, and 1921.

Table 2 and especially the chart of tracks indicate that most of the recorded storms occur in longitudes 100° to 130° W. and latitudes 12° to 27° N. However it is not improbable that the entire area here shown is occasionally crossed by tropical cyclones. Certain it is that even in the midst of the large blank area between Hawaii and California gales are not lacking, although some such gales are due to steep barometric gradients on the side of the Pacific high-pressure area rather than to local storms. However, most unusually steep gradients of this sort are closely related to cyclonic storms near by.

As to the courses followed by the storms: The chart indicates that most of them travel northwest or north in this region. However, a number have recurved and progressed varying distances toward the northeast. One, at least, has crossed to the Gulf of Mexico, and over it to Florida. Others such as the storm of September, 1921, have been traced as far as Newfoundland. Still other storms move due westward and some even west-south-westward. How far such westward moving storms may

⁶ A. Schück: Zur Kenntnis der Wirbelstürme in Beiträgen zur Meereskunde, p. 81, Hamburg, 1906.

⁷ Redfield: loc. cit.

⁸ Loc. cit., Tafel IV.

⁹ Atlas für den Stillen Ozean, Deutsche Seewarte, Hamburg, 1906.

¹⁰ U. S. Weather Bureau, 1913.

¹¹ U. S. Hydrographic Office, 1921.

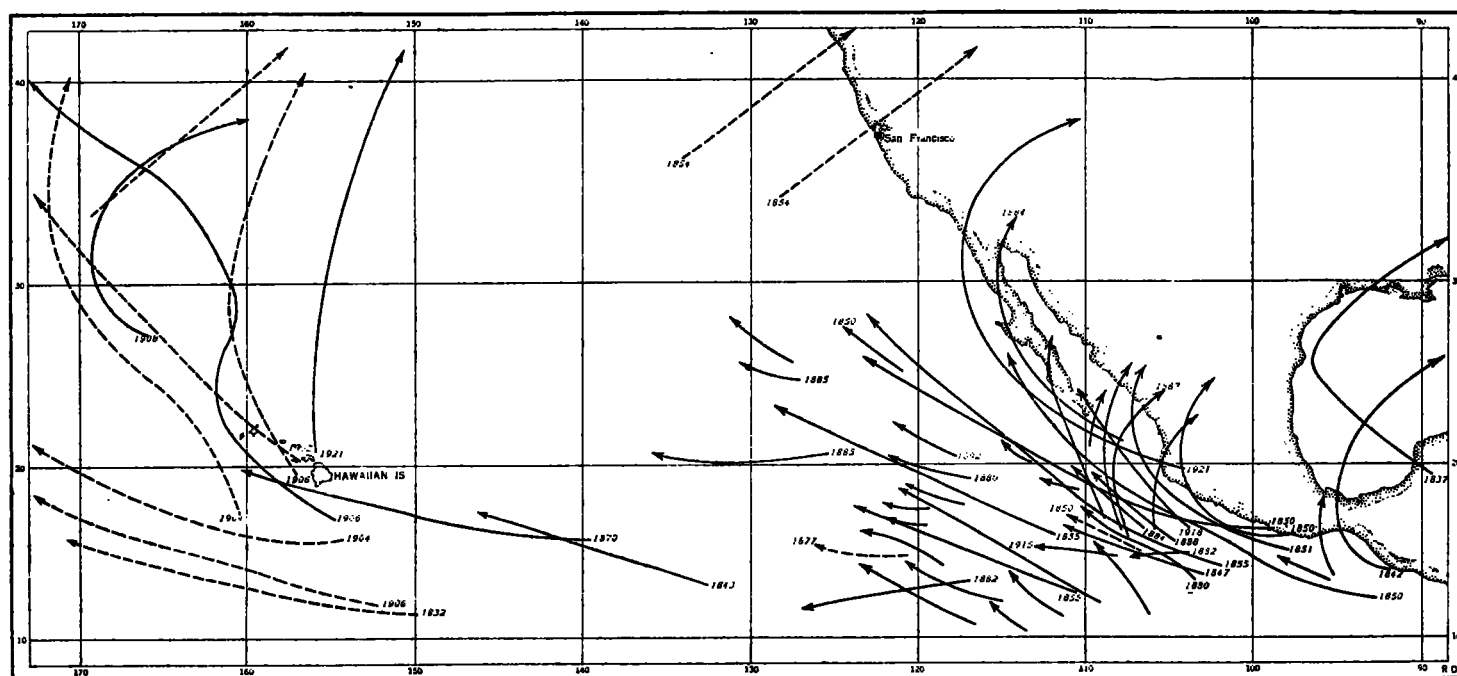


FIG. 1.—Approximate tracks of about 60 tropical storms in the Pacific Ocean between Mexico and Hawaii. Solid lines, June to October, inclusive; dashed lines, November to May, inclusive.

sometimes go before recurving is unknown, but Kimball suggests that some may cross the Pacific to Japan.¹²

As to velocity of movement, Redfield¹³ reports that some move slower than any he knew of in the Atlantic, but not slower than some in the Bay of Benegal. On the other hand, some of the recent storms, for which the information is rather full, as for example the severe storm of September, 1918, moved nearly 300 miles in 24 hours.

As to severity: Tropical cyclones in this region, as in all others, vary greatly in intensity. Unusually severe storms are uncommon. The average storm is not

so severe perhaps as the average typhoon, or West Indian hurricane, and many are not destructive to shipping, just as many typhoons and West Indian hurricanes are not destructive to shipping. But on the other hand the records indicate that scores of boats have been wrecked by storms in the northeast Pacific, and it does no good to try to ignore these storms or to say that they afford no appreciable danger.

As to frequency, the list given above suggests that two or more tropical cyclones occur on the average each year off the west coast of Mexico. Twenty-six are recorded in 11 years, 1849-1859, and 24 in 13 years, 1880-1892. In one year, 1855, seven were recorded.

¹² J. H. Kimball, *loc. cit.*

¹³ Redfield, *loc. cit.*

A METHOD FOR THE CALCULATION OF NORMAL FROST DATES FROM SHORT TEMPERATURE RECORDS.

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[Brown Co., Berlin, N. H., July 8, 1922.]

A few months ago the writer had occasion to examine the records of five or six cooperative Weather Bureau stations in a certain small area with a view to estimating frost risk in that area. It chanced that some of these stations had only a short record, and, accordingly, the direct averaging of frost dates, etc., was out of the question as a method of any trustworthiness, especially since some of those few years had passed without any recorded frost. Under these circumstances it was necessary to use an indirect method of computation, based on the temperature record. The occurrence of a minimum temperature of 32° or below was taken as the equivalent of a killing frost.¹ Then from the available data the smoothed curve of "normal" daily minimum temperature was drawn, and the dispersion of actual minima about the mean minimum determined. With this material it was possible to calculate the frost data usually required, namely, probable dates of first and last frost, and length of growing season in four out of five years. A search of the literature on the mathematical treatment of frost data has failed to reveal any reference to previous use of the method in question.

The fundamental idea on which the method is based is that the "average" date of, say, the first killing frost in the fall is the mean abscissa of a curve whose ordinates represent the joint probability that frost will occur and that it shall not previously have occurred (since spring); in other words, the probability that the first frost will occur, plotted against date, is the same curve as the frequency distribution of first frost over, say, a 100-year period, and will correspond to the same average date. It should be noted that given two stations with identical normal daily minimum temperature curves, frost will occur first at the station where actual temperatures disperse most widely about the mean; the calculation could be very greatly simplified if this dispersion could be assumed to be Gaussian, but in fact it is found to be so asymmetrical that the Gaussian formulas are useless, and graphical treatment is preferable in this case to the use of either Pearson's or Tolley's skew formulas.

¹ The use of a temperature criterion of frost occurrence, while suffering from the grave drawback that damage to vegetation is not a direct function of temperature alone, still possesses several important advantages. (See, for instance, "Killing frost and length of growing season in various section of Kentucky," Ferdinand J. Walz, *MO. WEATHER REV.*: 45, 348, 1917, and "Weather forecasting the United States," W. B. No. 583, p. 178.) Mr. William G. Reed comments in a private communication as follows: "In general, we have found that temperature methods of determining frost dates are more definite, and probably more accurate, than reports of killing frost. * * * Killing frost is really not a meteorological phenomenon at all, but it is so tied up with various questions of plant pathology that the term means different things at different times and different places."

The smoothed curve of normal daily minimum temperature can not, of course, be determined very accurately from only 4 or 5 years record. A more precise method which is usually possible consists in utilizing the monthly histogram giving the normal daily minimum of a near-by station of 20 years' or longer record, averaging the differences in monthly means at the two stations during the 4 or 5 years of simultaneous record at both stations, applying the differences so found to the long record, and smoothing the corrected histogram to a continuous curve.

The dispersion of actual minima about the mean is determined directly in ogee form, recording as "probability that the temperature will be lower than n degrees above or below the mean." Table 1 summarizes the dispersion of August and September minima about the mean determined from Figure 1. The data are taken from the records of the cooperative observer at Berlin, N. H., 23 years observations being available from which to draw the mean curve.

TABLE 1.

Deviation from mean.....	Negative.					Positive.				
	25-20	19-15	14-10	9-5	4-0	1-5	6-10	11-15	16-20	21-25
Number of cases.....	0	6	20	37	49	63	50	17	2	0
Number of cases with lower temperature than given deviation.	0	6	26	63	112	174	224	241	243	243
Probability that temperature will be lower than given number of degrees from the mean.....	0	0.025	0.107	0.260	0.461	0.715	0.920	0.992	1.00	1.00

The ogee curve is drawn through plotted points -15, 0.025; -10, 0.107; -5, 0.260; 0, 0.461; +5, 0.715, etc. (See fig. 2.)

The probability of frost occurrence can now be plotted against date by determining at, say, five-day intervals, the distance of the mean minimum temperature curve from the 32° line and reading from the ogee curve (fig. 2) the probability of occurrence of such a deviation from the mean. Figure 3 was drawn in that way from the given data.

It is now necessary to determine the probability that on any given date frost shall not previously have occurred; the values of Figure 3, subtracted from unity,